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Design and Analysis of Outer Mold Line Close-outs for the Max Launch Abort System (MLAS) Flight Experiment

Jessica A. Woods-Vedeler, Jeffrey R. Knutson, and David M. Schuster
NASA Langley Research Center, Hampton, Virginia

Erik D.Tyler
Analytical Mechanics Associates, Inc., Hampton, Virginia

March 2010

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National Aeronautics and
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Langley Research Center
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ABSTRACT

In 2007, the NASA Exploration Systems Mission Directorate (ESMD) chartered the NASA Engineering Safety Center (NESC) to demonstrate an alternate launch abort concept as risk mitigation for the Orion project's baseline "tower" design. On July 8, 2009, a full scale, passive aerodynamically stabilized Max Launch Abort System (MLAS) pad abort demonstrator was successfully launched from NASA Goddard Space Flight Center's Wallops Flight Facility. Aerodynamic close-outs were required to cover openings on the MLAS fairing to prevent aerodynamic flow-through and to maintain the MLAS OML surface shape. Two-ply duct tape covers were designed to meet these needs. The duct tape used was a high strength fiber reinforced duct tape with a rubberized adhesive that demonstrated 4.6 lb/in adhesion strength to the unpainted fiberglass fairing. Adhesion strength was observed to increase as a function of time. The covers were analyzed and experimentally tested to demonstrate their ability to maintain integrity under anticipated vehicle ascent pressure loads and to not impede firing of the drogue chute mortars. Testing included vacuum testing and a mortar fire test. Tape covers were layed-up on thin Teflon sheets to facilitate installation on the vehicle. Custom cut foam insulation board was used to fill mortar hole and separation joint cavities and provide support to the applied tape covers. Flight test results showed that the tape covers remained adhered during flight.

NOMENCLATURE

A	Area, in^2
C_p	Pressure coefficient
M	Mach number
P	Perimeter, in
p	Static pressure, psi
q	Dynamic pressure, psf

List of Acronyms

CEV	Crew Exploration Vehicle
CFD	Computational Fluid Dynamics
CLV	Crew Launch Vehicle
ESMD	Exploration Systems Mission Directorate
IML	Inner Mold Line
FF	Forward Fairing
LaRC	NASA Langley Research Center
MLAS	Max Launch Abort System
NESC	NASA Engineering and Safety Center
OML	Outer Mold Line

INTRODUCTION

In 2007, the NASA Exploration Systems Mission Directorate (ESMD) chartered the NASA Engineering Safety Center (NESC) to demonstrate an alternate launch abort concept as risk mitigation for the Orion project's baseline "tower" design. Orion is part of the NASA Constellation Program architecture. The alternate concept, known as the Max Launch Abort System (MLAS), would be capable of extracting the Crew Exploration Vehicle (CEV) from the launch vehicle at any time from crew ingress at the launch pad through staging and successful ignition of the second or upper stage of the Crew Launch Vehicle (CLV**).** On July 8, 2009, a full scale, passive aerodynamically stabilized MLAS launch abort demonstrator was successfully launched from NASA Goddard Space Flight Center's Wallops Flight Facility following nearly two years of development work on the launch abort concept.

For MLAS, Outer Mold Line (OML) close-outs were required to restore the approximate OML of the vehicle in several areas where the composite fairing had been cut away to accommodate other subsystem components. Such covers were needed over the eight separation joints, two forward fairing mortar hole openings, the confluence fitting opening and the eight fin root gaps. The locations of these opening in the final flight configuration are shown in Figure 1.

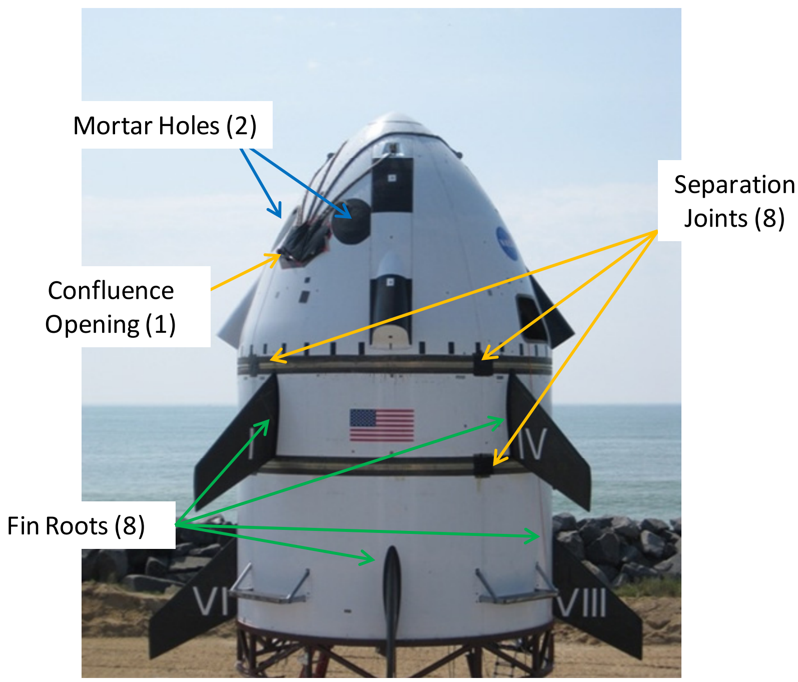


Figure 1. Final MLAS flight configuration on the launch stool showing locations of close-outs.

The purpose of the covers was to reduce flow disturbance and interior venting that could result from such openings and to minimize the potential for cavity resonances. This paper describes the design, analysis, testing and installation required for development of the OML covers. It is noted that while product brand names are indicated, NASA does not specifically endorse use of these products or guarantee their performance.

DESCRIPTION OF OML OPENINGS

Mortar Hole Openings

The mortar hole openings were locations of major venting to the vehicle interior. The goal in covering these openings was to aerodynamically seal the opening to prevent flow-thru on ascent while not impeding mortar firing. The openings were ellipses with measured dimensions of a=26.75 in and b=17.25 in, where a= major axis and b=minor axis. The area of an ellipse is given by

$$A = \pi ab / 4$$

The perimeter of an ellipse is given by

$$P = \pi \sqrt{2\left(\frac{a^2}{4} + \frac{b^2}{4}\right) - \left(\frac{a}{2} - \frac{b}{2}\right)^2}$$

For the mortar holes, A= 362.41 in^2 and P=69.92 in. The diameter of the circular mortar canister was 13 in. Figure 2 shows an unfilled and uncovered mortar hole opening. The interior of the Forward Fairing (FF) can be seen through the opening.

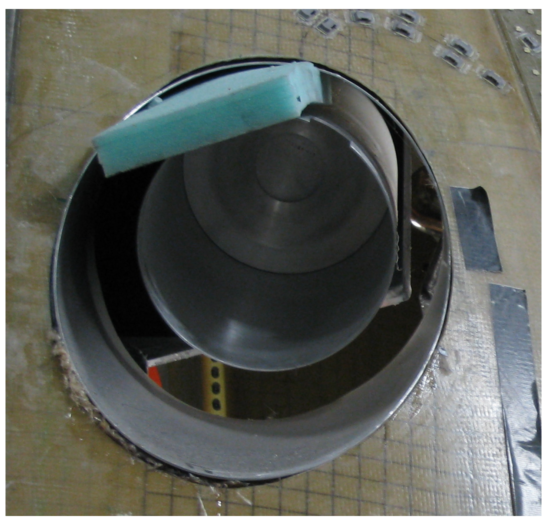


Figure 2. Mortar hole opening and empty mortar canister (center of hole).

Separation Joint Openings

The separation joint openings were also vented to the vehicle interior. The goal was to aerodynamically seal the openings to prevent flow-thru and the potential onset of cavity resonance. The eight separation joint openings were nominally 4 in x 7 in wide with P= 22 in and an A=28 in^2. Figure 3 shows approximate locations of the openings relative to fin locations. Figure 4 shows the uncovered separation joint openings prior to installation of the real frangible joint, initiators and detonation cord.

Fin Root Gaps

Fins had 0.5 in gaps from coast and boost skirt surfaces as shown in Figure 5. Gaps were not vented into the interior. So, the main goal was to seal gaps to prevent flow-thru effect at the fin roots that can reduce the aerodynamic effectiveness of the fins.

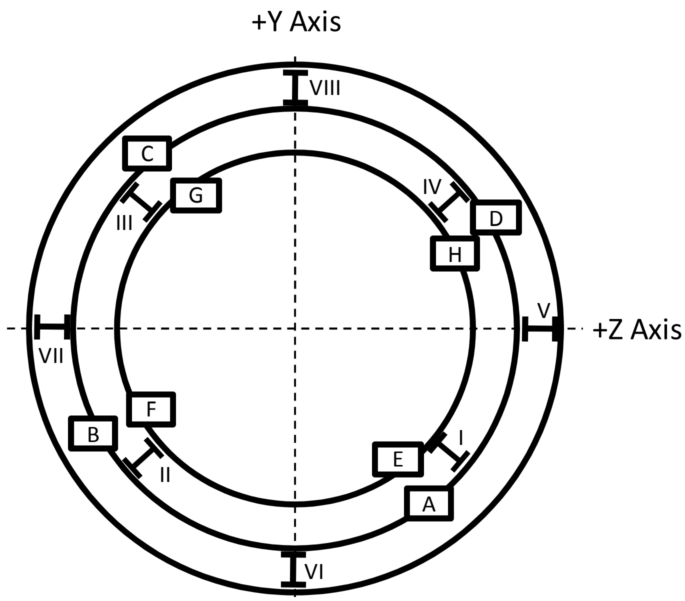


Figure 3. Illustration showing labels (A-H) and approximate locations of separation joint openings relative to fins (I-VIII).

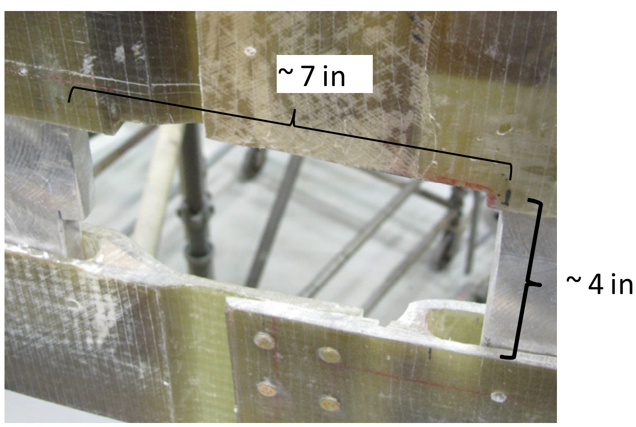


Figure 4. Typical separation joint opening (prior to installation of frangible joints, NASA Standard Initiators (NSI) and detonation cords).

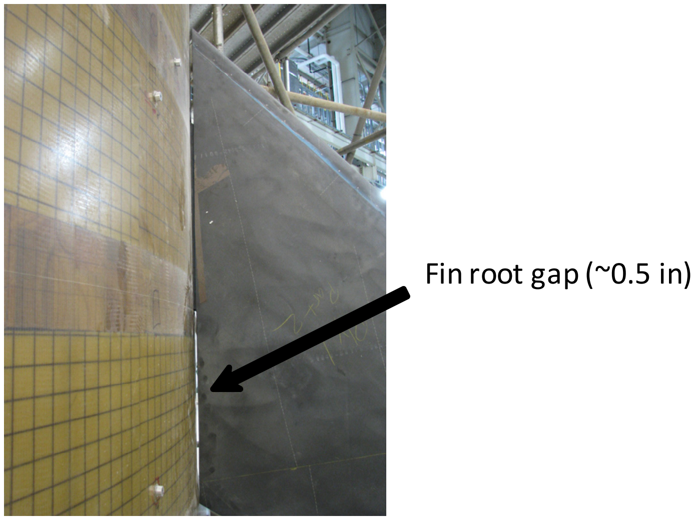


Figure 5. Fin Root Gaps

Confluence Opening

The location and geometry of the confluence opening is shown in Figure 6 and summarized in Table I. The opening was measured to be approximately 7 in deep. A photograph of the uncovered confluence box containing drogue parachute harnesses and confluence fitting is shown in Figure 7.

Table 1. Confluence opening geometry

	Design Dimensions	Actual Measured Dimensions
Height (A), in	23.20	22.50
Width (B), in	30.90	30.00
Upper corner hypotenuse, in	11.60	11.50
Leg of upper corner triangle, in	8.20	8.13
Area of upper corner, in^2	53.82	52.90
Lower corner hypotenuse, in	9.00	8.50
Leg of lower corner triangle, in	6.36	6.01
Area of lower corner, in^2	32.40	28.90
Perimeter, in	91.13	88.43
Area, in^{2*}	544.43	511.40

* assumes equal height and base of corner

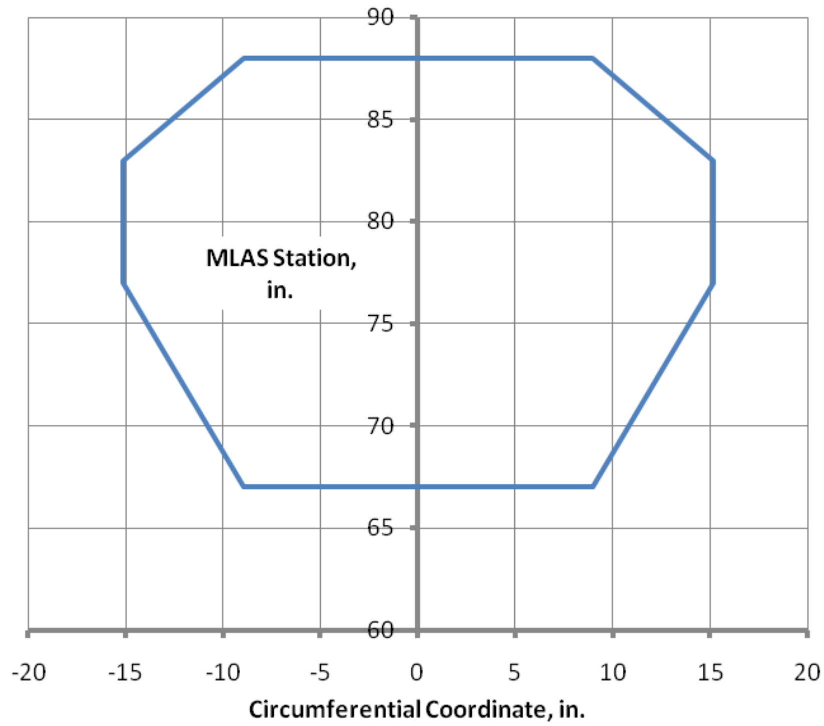


Figure 6. MLAS confluence cavity geometry (upside down view).

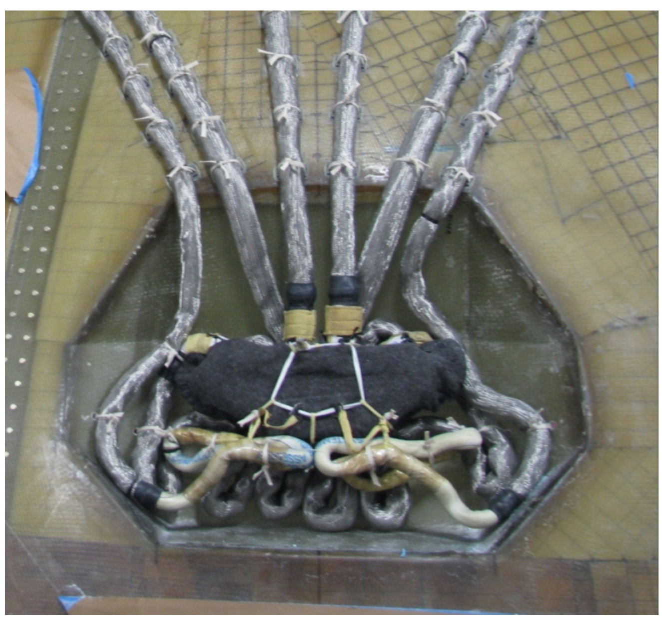


Figure 7. Cavity with parachute harnesses and confluence fitting.

APPROACH

The approach used to develop the OML cover concept involved design, testing, and analysis. In particular, a tape trade study was performed to evaluate the tape adhesion strength to the anticipated OML surface. Two tapes were carried forward from the trade study into a vacuum test to evaluate their performance in a tape cover design adhered over an open cavity and under normal pressure load. During the vacuum testing, foam fill designed to support the tape covers in large openings was also experimentally evaluated to demonstrate their integrity under load. Based on assumptions regarding tape cover behavior under normal load, an analysis of anticipated ascent loads obtained from CFD was performed.

RESULTS OF DESIGN AND TESTING

OML Cover Design

The OML close-out concept needed to be an easy to fabricate and apply adhesive cover that provided a conformal fit to the OML, remained adhered during ascent and did not impede execution of other vehicle subsystem operations. In particular, the close-outs needed to fail easily during ring separation and mortar firing associated with turn-around drogue chute deployment.

To meet these needs, the cover was constructed of two layers of duct tape laid up with the individual tape strips overlapped 0.5 in and oriented approximately 90 degrees to each other. The tape was to be bonded to the vehicle surface with an approximately 6 in margin around the entire confluence and mortar hole cavities and 4 in margin around the separation joint openings. As shown in Figure 8, the covers were laid up on a 0.015 in thick non-stick Teflon® sheet to facilitate layup and installation of the cover. The center section of the Teflon sheet remained adhered to the tape cover to prevent the cover from adhering to components stored in the cavity.

Peel-Testing

Candidate tapes for the covers were identified by reviewing technical specifications of commercially available tapes based on adhesion strength and acceptable temperature range. Peel-testing was then performed on 10 different tapes in order to compare their adherence performance on the painted vs. unpainted composite surface. Performance based on adhesion time (hours vs. days) was considered in the test trade matrix as well. Table 2 contains a summary of peel-test results for the 10 tapes that were tested. The peel strength was defined as the weight under which the onset of peeling was observed. Figure 9 shows the test setup for peel-testing.

As shown in Figure 10, the adhesion strength was seen to be significantly stronger on the unpainted surface than the painted (enamel) surface. As a result of this, all regions of the OML that were designated to receive a tape cover, including the confluence opening, had paint exclusion zones around the opening to maximize tape cover adhesion strength. Test results showed that Gorilla Tape® demonstrates approximately 4 lbs/in tape width adhesion strength on an unpainted fiberglass surface after approximately 3 days application time. Adhesion time was an important factor and it was recommended that tape covers be installed as early as possible on the vehicle to maximize adhesion performance.

Gorilla Tape® and Nashua® 357 (aka "Wallops Rocket Tape") tapes were selected for vacuum testing. The Lamar™ 213 tape (aka "Dryden Mach Tape") was not selected for further testing due to rapid unstick on initiation of peel and concern for tearing in this particular application.

Figure 8. Mortar hole cover lay-ups showing Telflon® back sheet (right).

Figure 9. Peel-test set-up.

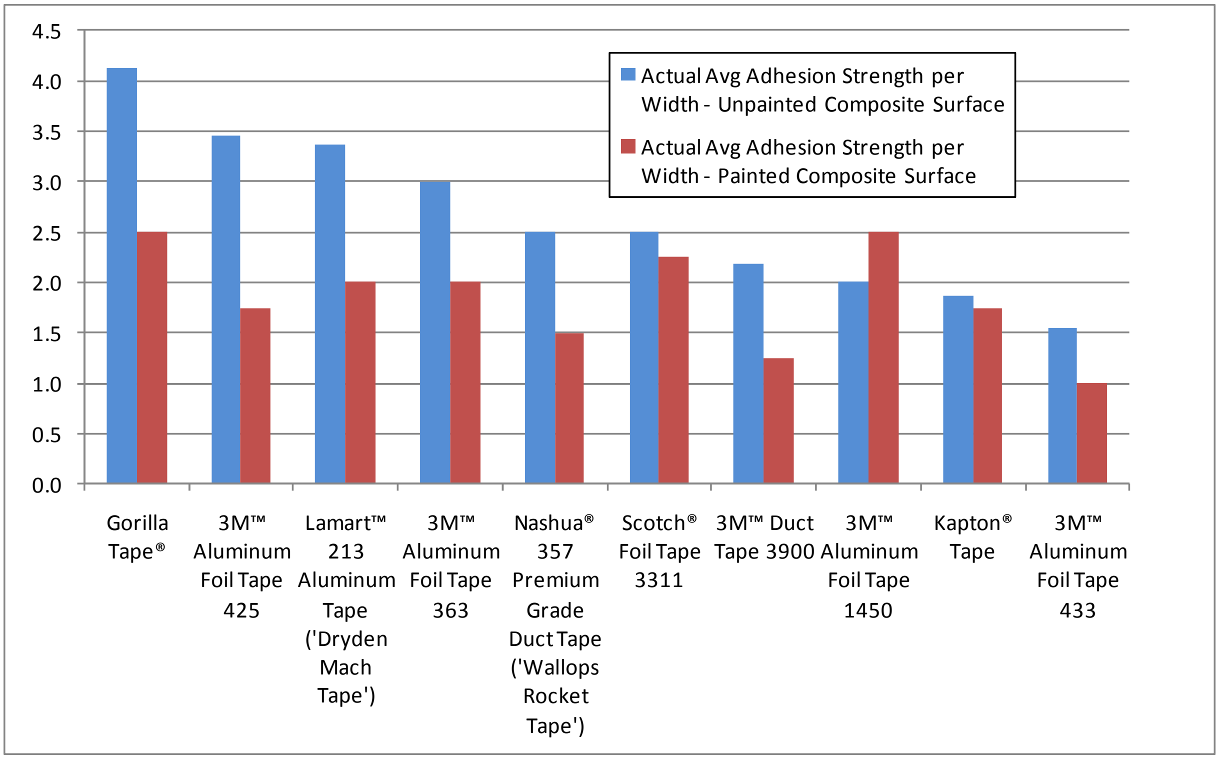


Figure 10. Tape adhesion test results.

Table 2. Results for Peel-Tested Tapes

Product	Adhesion Strength to Steel - Spec (lb/in)	Actual Avg Adhesion Strength per Width - Unpainted Composite Surface	Actual Avg Adhesion Strength per Width - Painted Composite Surface	Summary Comments
Gorilla Tape®	unknown	4.1	2.5	Strong hold. Very slow unstick. Slightly higher adhesion with longer time. Slightly lower stick on painted surface. Difficult to tear. Drawback is black color. Better on unpainted surface than painted surface.
3M™ Aluminum Foil Tape 425	2.94	3.5	1.8	Competitive with gorilla tape on unpainted surface but not painted surface. Effect with time about the same. Better on unpainted surface than painted surface.
Lamart™ 213 Aluminum Tape **('Dryden Mach Tape')**	2.5	3.4	2.0	Better than spec on unpainted surface. Half the adhesion to painted surface vs unpainted surface. Competitive with Gorilla Tape® on unpainted surface. Significantly higher adhesion with time. Tears easily in shear. Rapid unstick after unstick start.
3M™ Aluminum Foil Tape 363	4.19	3.0	2.0	Good to 600F. Very expensive and hard to get.
Nashua® 357 Premium Grade Duct Tape (**'Wallops Rocket Tape'**)	3.44	2.5	1.5	Gorilla tape is 40% better than nashua tape.
Scotch® Foil Tape 3311	5.63	2.5	2.3	Less than half advertised adhesion strength. Time of adhesion has no effect. About the same on painted and unpainted surfaces.
3M™ Duct Tape 3900	3.50	2.2	1.3	Very poor adhesion. Time of adhesion improves strength but still less than spec.
3M™ Aluminum Foil Tape 1450	7.13	2.0	2.5	Significantly less than spec performance.
Kapton® Tape	2.00	1.9	1.8	Not competitive with other tapes. Generally below spec performance. Performs better on painted surface than unpainted surface.
3M™ Aluminum Foil Tape 433	2.50	1.6	1.0	Not competitive with other tapes. Adhesion strength significantly less than spec. equally good on painted and unpainted surface.

**strength = lb/in width*

Vacuum Testing

The tape cover concept was tested in a vacuum facility to assess its ability to remain attached under sustained pressure loads. A 4 in x7 in hole was cut in a 20 in x 20 in singly curved, unpainted section of the boost skirt's foam core and fiberglass composite material. As shown in Figure 11, the machined fairing was bolted to an aluminum cylinder that was used as a plenum for pressure regulation. Rubber washers were used to accommodate the curved interface and consumer grade silicon caulking was used to seal gaps. The pressures within the plenum and in the vacuum chamber were regulated to simulate representative loads anticipated to act on the cover during flight. The tape covers were tested to differential pressures of +- 6 psi or until venting and pressure equalization across the covers occurred.

The size of the opening in the test article was 4 in x7 in for a total differential pressure exposed area of 28 in^2. At +/- 6 psi, the total pressure load applied to the tape cover was 168 lbs. The pressure load was reacted into the tape/fairing interface around the perimeter of the opening. The perimeter of the opening was 22 in which would have resulted in an applied normal load around the perimeter of +/- 7.6 lbs/in at the maximum planned test conditions.

As shown in Figure 12, testing confirmed that the two-ply Gorilla Tape® cover with the 4 in margin remained adhered to the fiberglass test panel for almost 10 seconds and to a pressure of 5.6 psi, which is a perimeter load of about 7.1 lbs/in. The cover did not fail catastrophically. Instead, failure was observed to be a relatively slow process of peeling and venting of the cover. Since the interior volume expands during peeling while the exterior pressure is changing at a constant rate, it appears that the peeling may have initiated at 3.6 psi when the slope of the delta pressure curve in Figure 12 changes. This corresponds to a perimeter load of 4.6 lb/in which is approximately consistent with the peel-test results for Gorilla Tape®. The apparent increased adhesion strength for onset of peel over peel-test results may be due to the different geometric configuration of the cover. Figure 13 shows pillow peeling of the cover under an outward applied pressure. Failure occurred when the ellipsoid pillow reached the shortest margin of the cover away from the hole and vented.

A 4.6 lb/in perimeter load is equivalent to a 101 lb applied normal load. The plot in Figure 12 shows that the tape cover reaches this load at approximately 1.9 seconds into the test and the curve changes slope at this point. The sample vents at approximately 9.5 seconds. This test was performed with a 4 in tape margin. The opening remained sealed for approximately 7.6 sec above an observed 4.6 lb/in peel strength for the Gorilla Tape®. If one could assume a constant applied pressure and peel rate, this would equate to 0.53 in/sec peeling. In reality, since the ascent pressure differential never reaches 6 psi that was used during testing, the peel rate would in fact be slower and is not constant.

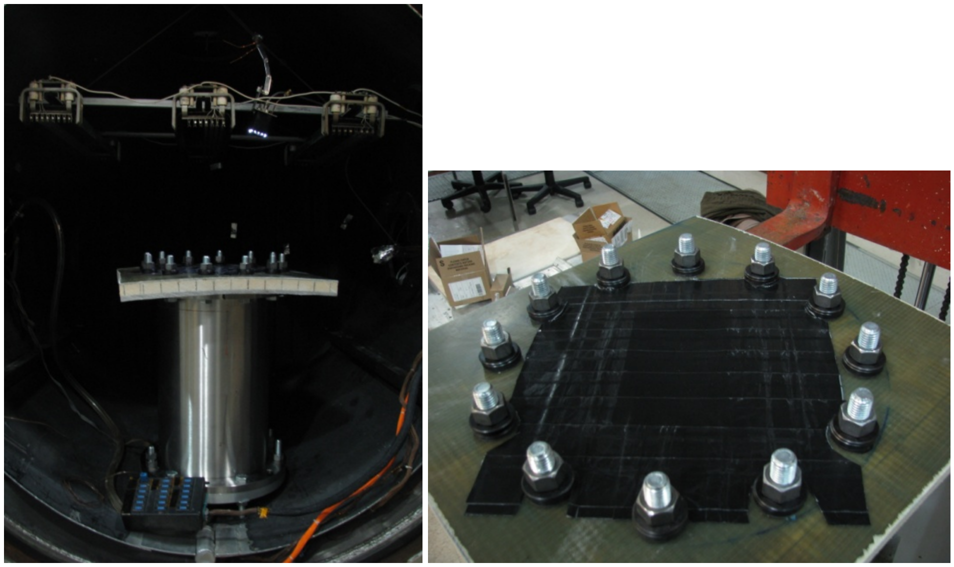


Figure 11. Experimental test setup in vacuum facility.

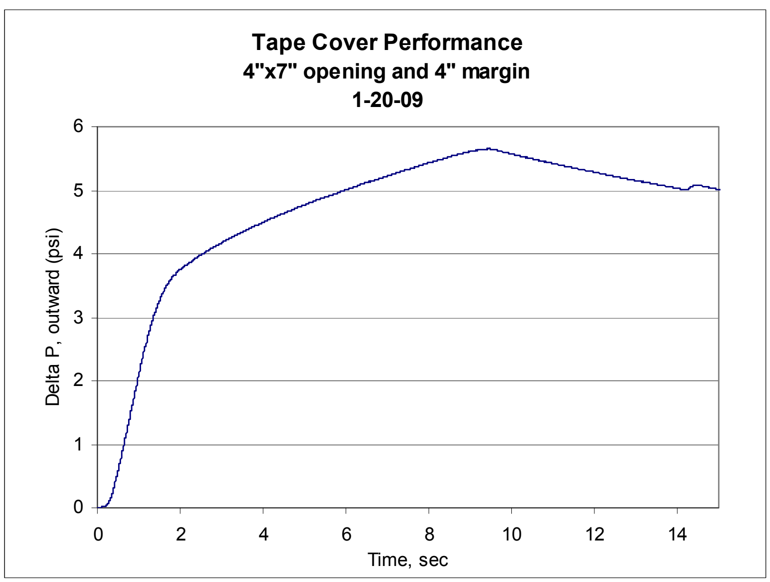


Figure 12. Outward test pressure versus time for Gorilla Tape® cover.

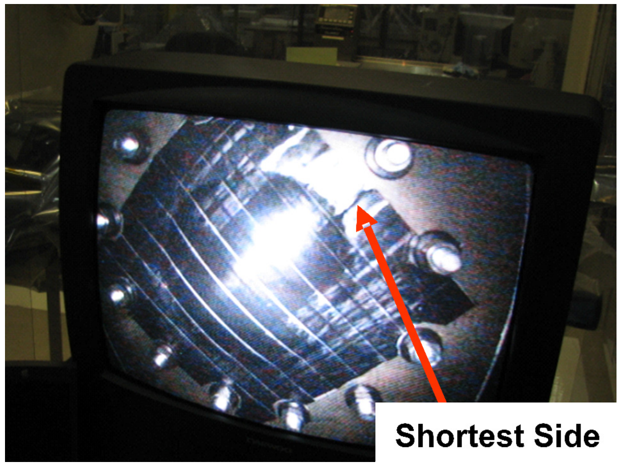


Figure 13. Image of tape cover peeling under outward pressure load.

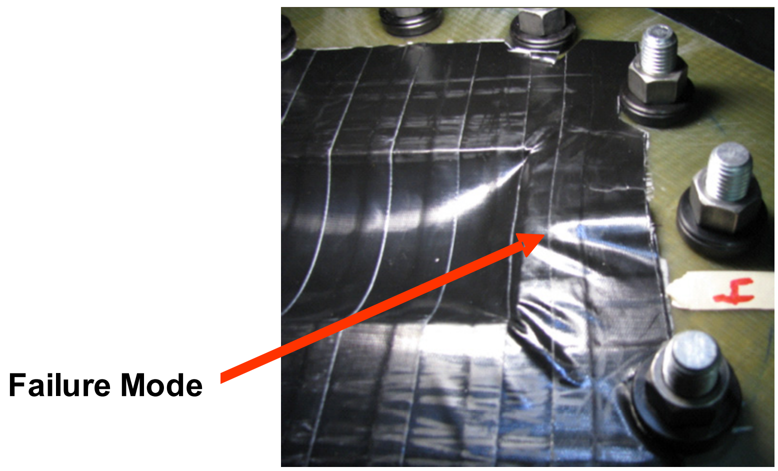


Figure 14. Image of tape cover collapse under inward pressure load.

Under inward loads, the tape cover failure mode is shown in Figure 14, and a representative inward pressure versus time plot is shown in Figure 15. In the case of an inward pressure, the cover tends to pull in at one side until venting occurs without catastrophic release of the whole cover. In some cases, the inward pressure did not cause venting and the system reached and maintained the maximum inward test pressure despite inward deformation of the cover.

The Nashua® 357 did not perform as well in that the tape held to an outward pressure of 4.6 psi and then failed rapidly. The comparison is shown in Figure 16. Adherence time was also a factor and the Nashua® 357 tape performance increased to a failure pressure of 4.6 psi after 3 days application time. The short duration time indicated in Figure 16 is on the order of several hours. Thus, the Gorilla Tape® was selected for use in tape cover construction.

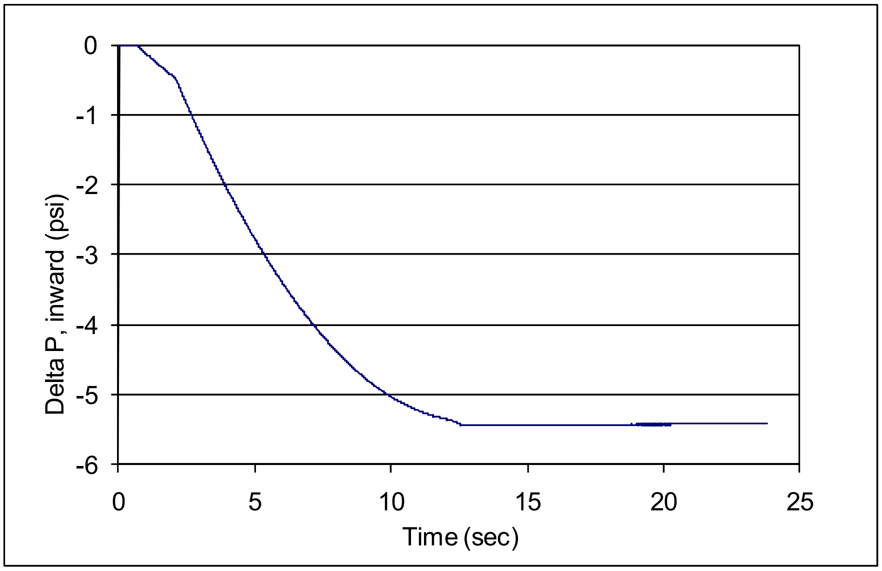


Figure 15. Inward test pressure versus time for Gorilla Tape® cover.

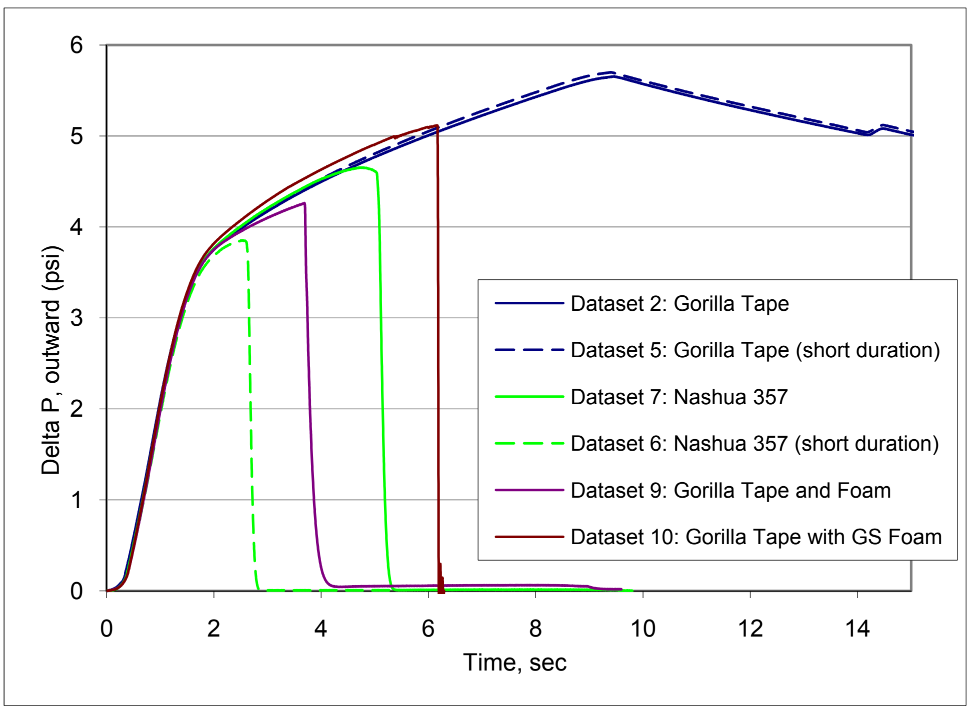


Figure 16. Comparison of Gorilla Tape® with Nashua® 357 and with foam fill options.

An approach to foam fill the gaps that were created by the frangible joints on all sides of the separation joint opening was also evaluated. Half inch thick aluminum plates were bolted to the test fixture and foam insulation board was custom fit to the sides. The foam was held in place using GE ™ Silicon II caulking that was allowed to cure overnight. Figure 17 shows the test set-up prior to application of the Gorilla Tape® cover. During testing with the same pressure profile as used previously, the Gorilla Tape® and foam panel held to 4 psi with a rapid failure via the foam interface as shown in Figure 16. The tape cover remained attached at other areas. When the pressure was reversed to an inward normal direction,

the Gorilla Tape® re-adhered to the foam creating an aerodynamic seal. Spray in foam, Great Stuff™ for Big Gaps, was also evaluated. With a pressure reversed to inward, the Gorilla Tape® did not re-adhere to the spray-in foam and, thus, did not re-seal and maintain a pressure differential across the cover.

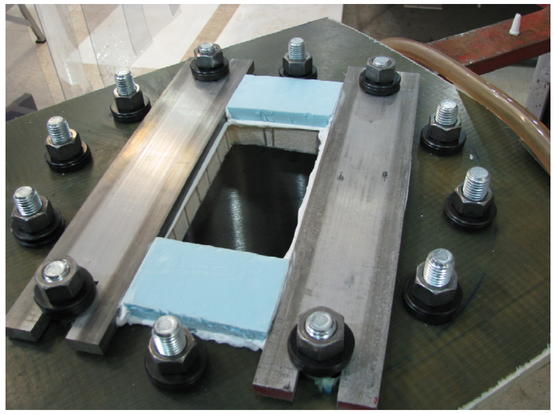


Figure 17. Test set-up of the simulated frangible joint gap filler.

In summary, vacuum testing demonstrated that Gorilla Tape® was able to meet the requirements of this application. From the test results, it was recommended that the side depth of tape cover should be consistent with peel rate and duration of pressure delta. Tape adhesion time is also an important factor. Tape covers should remain in place for at least 2 days prior to 'use' to maximize the adhesion strength of the tape cover.

Mortar Fire Testing

In order to evaluate whether or not the OML close-out over the mortar holes would impede mortar firing, the Landing Systems team devised a mortar fire test using a section of discarded forward fairing. The test included an OML foam insert and mortar hole cover. Results showed that the tape cover did not impede the mortar firing. Photographs of the mortar hole opening and tape cover are shown in Figure 18. Additional test results can be obtained from Landing System documentation in the NESC Final Assessment Report [1].

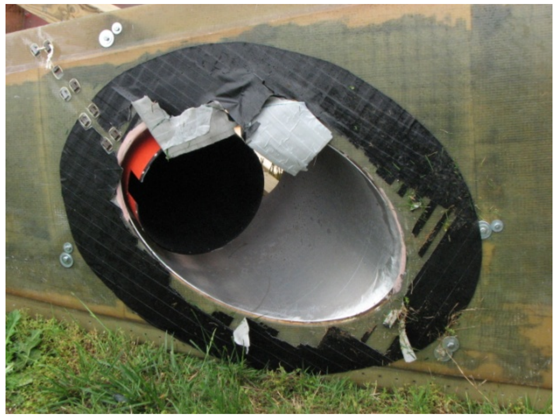
ANALYSIS

Based on the tape cover performance observed during peel-testing and vacuum testing, analysis was performed to predict the ability of tape covers to remain attached to the MLAS vehicle during ascent. In this section, CFD loads are presented based on the estimated vehicle trajectory and performance analysis is presented for each opening cover.

Aerodynamic Flight Loads

To estimate the aerodynamic load on the cover during flight, fairing surface pressures were obtained using CFD. Figure 19 shows the fairing surface pressure coefficient distribution from CFD along a line through the center of the confluence fitting. Data are presented for Mach 0.50 and 0.70 at 10 degrees

angle-of-attack. The 3-σ maximum dynamic pressure trajectory (MLAS-D2-6E-95deg-MaxQ-Rev20090514) used is shown in Figure 20. The figure indicates that the vehicle attains a maximum dynamic pressure of 610 psf.



(a) Mortar hole opening after mortar firing.

(b) Back-side of tape cover fragment after mortar firing that shows Teflon® center.

Figure 18. Mortar fire testing.

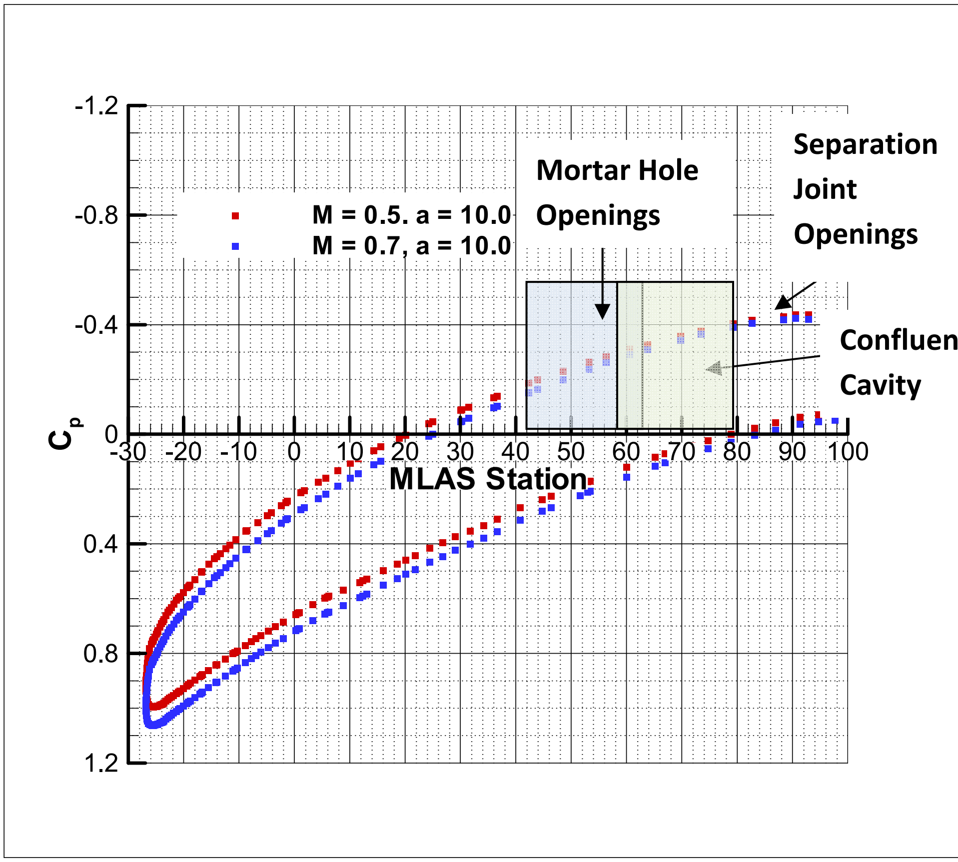


Figure 19. Forward Fairing pressure distribution from CFD.

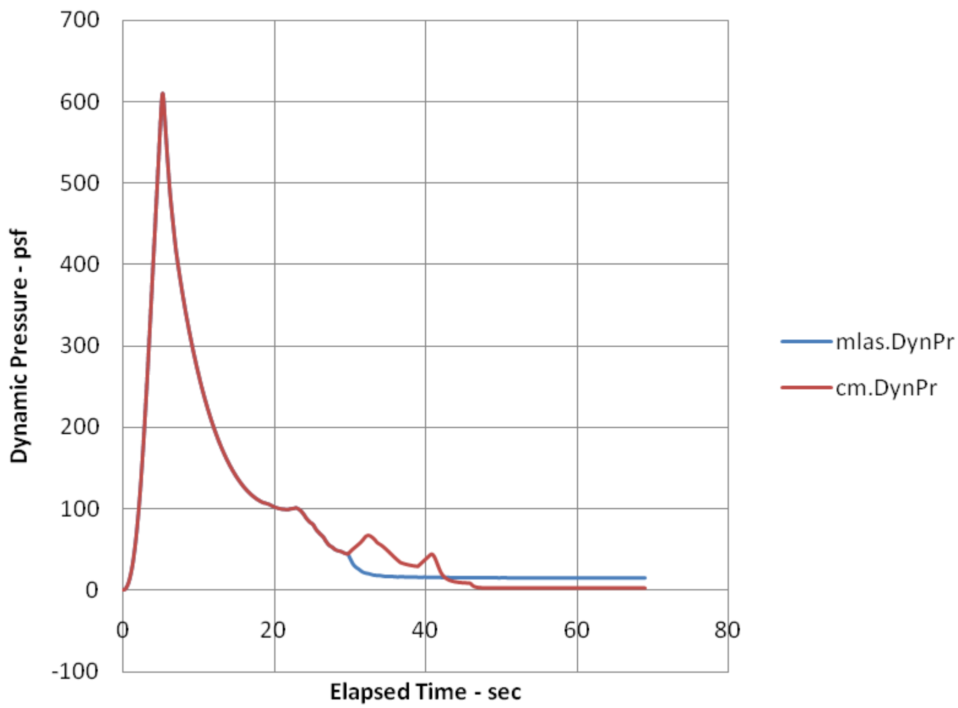


Figure 20. Dynamic pressure trajectory for 3-σ Max q trajectory.

Performance Analysis

Confluence Opening

Over the confluence cavity (approximately X= 67 to 88 in), the pressure coefficient varies from approximately -0.35 to -0.41, or an average of -0.38 as shown in Figure 19. From Table 1, the confluence opening has an area of 511 in^2 and a perimeter of 88.43 in. Using the average pressure coefficient of -0.38, the maximum dynamic pressure of 610 psf and an area of 511 in^2, the total suction pressure load on the cover is -1.61 psi. This equates to approximately 823 lbs normal force acting on the cover. Converting the applied load into a 'pounds per perimeter length' unit, the tape cover will have to carry a load of approximately 9.31 lb/in.

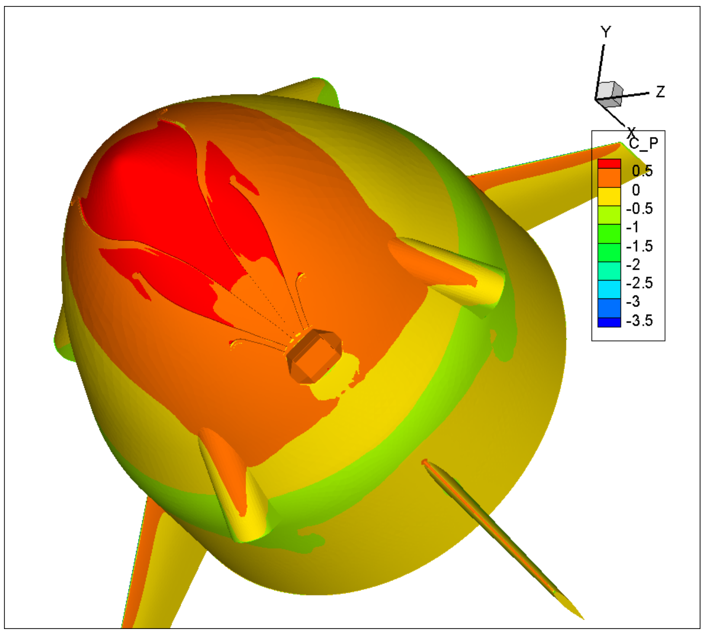


Figure 21. CFD analysis of confluence opening with no cover.

Since the tape covers began to peel at about 4.6 lb/in in testing, it was assumed that the tape cover would peel under a 9.31 lb/in flight load. The load corresponding to 4.6 lb/in boundary loading is 0.8 psi or 407 lb. Thus, the vehicle dynamic pressure threshold at which peeling would initiate is approximately 303 psf for a pressure coefficient of -0.38. For the worst case dynamic pressure trajectory considered in this analysis, the vehicle would first hit this dynamic pressure at approximately 3.4 sec into the flight and then pass back through this threshold at approximately 9 sec. Thus, the tape cover would be subjected to and must survive a peeling pressure for approximately 5.6 seconds of the 3-σ max q trajectory.

Assuming the 6 in. margin around the flight confluence cover provides additional peel time before becoming unsealed, there is a credible argument that the tape cover would remain sealed for at least 12 seconds above the 4.6 lb/in peel strength equivalent loading. This is double the amount of time anticipated in that range according to the 3-σ Max q trajectory. Even at this point, vacuum test observations indicate that the cover will largely remain adhered to the surface unless venting somehow allows airflow to enter the cover and facilitate peeling, a condition that was not tested. Finally, because the adhesion

performance of the tape on the surface tends to strengthen over time, it is anticipated that results presented herein are a conservative estimate of the actual performance that would be observed.

A concern that the confluence opening would cause a disturbance that may reduce the effectiveness of the coast fin located behind the opening was investigated. CFD results in Figure 21 show that such a disturbance does not occur based on the model assumptions. The model included the confluence opening well with a simple box located in the interior to represent the packaged parachute riser lines and confluence box.

Mortar Hole Openings

According to Figure 19, the average Cp for the mortar hole location (approximately X=50 to 67 in) is -0.3. At Cp= -0.3 and 610 psf, the mortar holes experience a loading of 461 lb normal force acting on the cover. This is equivalent to 6.59 lb/in along the mortar hole perimeter. Peeling initiates at 4.6 lb/in, which for Cp= -0.3 corresponds to 426 psf. From the trajectory, peeling would begin at 4.125 sec and last until 6.9 sec which is a 2.875 sec duration. With a 6 in margin, the same argument can made for the mortar hole covers as for the confluence opening cover. The covers will remain in place during ascent since there is insufficient time for peeling to occur through the margins. In this case, the time required for loss of cover due to peeling is approximately four times the duration above 426 psf.

Separation Joint Openings

From Figure 19, the worst case Cp for the separation joints is -0.4. At Cp= -0.4 and 610 psf, the separation joints experience a loading of 47.4 lb normal force acting on the cover. This is equivalent to 2.15 lb/in along the mortar hole perimeter. Since peeling would initiate at 4.6 lb/in, peeling does not occur at all for the separation joint openings due to ascent loads alone.

However, the separation joint openings are subject to an outward pressure that occurs during boost due to ignition overpressure. From discussions with the Propulsion Team, the expected outward pressure is 4 psi over 0.1 sec at ignition. This load is equivalent to 112 lb or 5.09 lb/in along the perimeter. This load is above the peel load, but the duration of time is insufficient to allow time for peeling. Instead, the impulsive load may cause tearing along the perimeter. Behavior of the covers under non-quasi-static loads was not quantified.

INSTALLATION

Mortar Hole Foam Fill

The mortar hole openings represented major aerodynamic venting of the forward fairing. As such, before covers were applied, it was necessary to actually fill the openings. To accomplish this, the openings were filled with custom fit, foam board insulation stacks as shown in Figures 22 and 23. For the OML, the foam board insulation was precut, stacked into the opening and sanded to the OML shape as shown in Figure 22. The stacked pieces were glued together with 3M™ Scotch-Weld™ Epoxy Adhesive DP-100 Plus (DP-100) but were free to slide in and out of the mortar hole opening so as not to impede mortar firing. For the IML, the foam board insulation was custom fit around the mortar canister and epoxied in place with DP-100 in order to create an aerodynamic seal. Silicone caulking was used to fill larger

openings on the IML exposed edges. Figure 8 showed the mortar hole covers with the removable Teflon® backing used on all OML close-outs.

Separation Joint Foam Fill

For the eight separation joints, foam board panel inserts sealed the side, top and bottom skirt joint gaps. While silicon caulking was used in the vacuum tests, DP-100, a two part epoxy, was used to fix the foam in place. The epoxy was used because caulking requires atmospheric moisture to cure and, thus, would not cure in regions of thick application. A photograph of a typical foam configuration is shown in Figure 24.

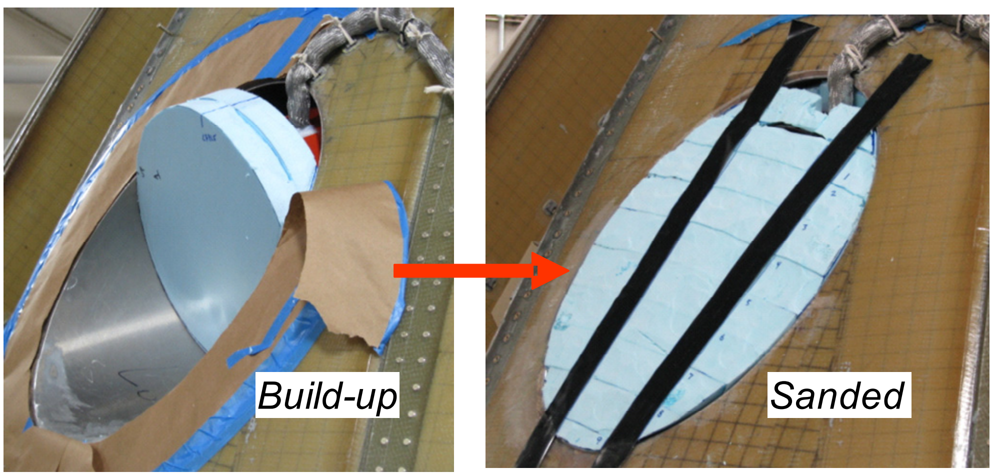


Figure 22. OML view of mortar hole foam fill.

Figure 23. IML view of mortar hole foam fill.

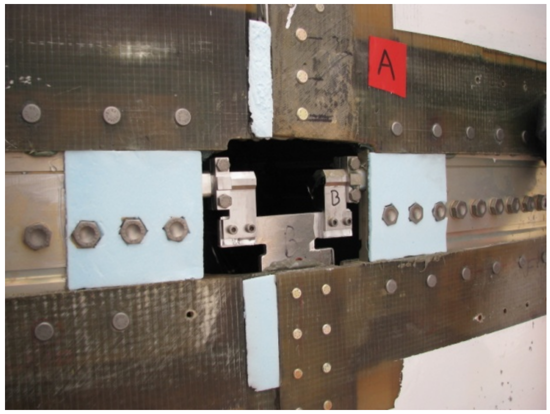
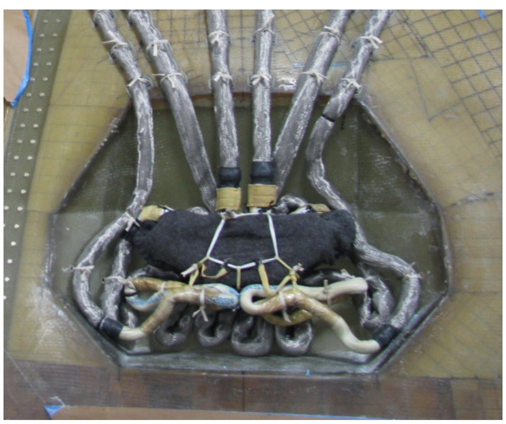


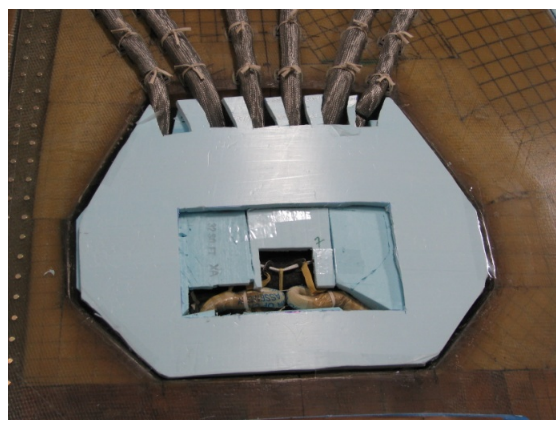
Figure 24. Final foam configuration in separation joints.

Confluence Opening Foam Fill

A view of the confluence foam installation is shown in Figure 25. An additional panel which covers the cable cut knives is not shown. Loose (i.e., not bonded) foam board was used to support tape cover. Cable cutters were shielded from any compressive load due to aerodynamic compressive forces that might act on the cover.

Figures 26 and 27 show the final recommended OML cover configuration.





(a) Filled confluence cavity. (b) Confluence cavity with foam fill.

(b) Cable cutters.

Figure 25. Recommended confluence cavity foam fill (tape cover not shown).

Figure 26. A fin root gap cover and two separation joint opening covers (C and G, as shown in Figure 3).

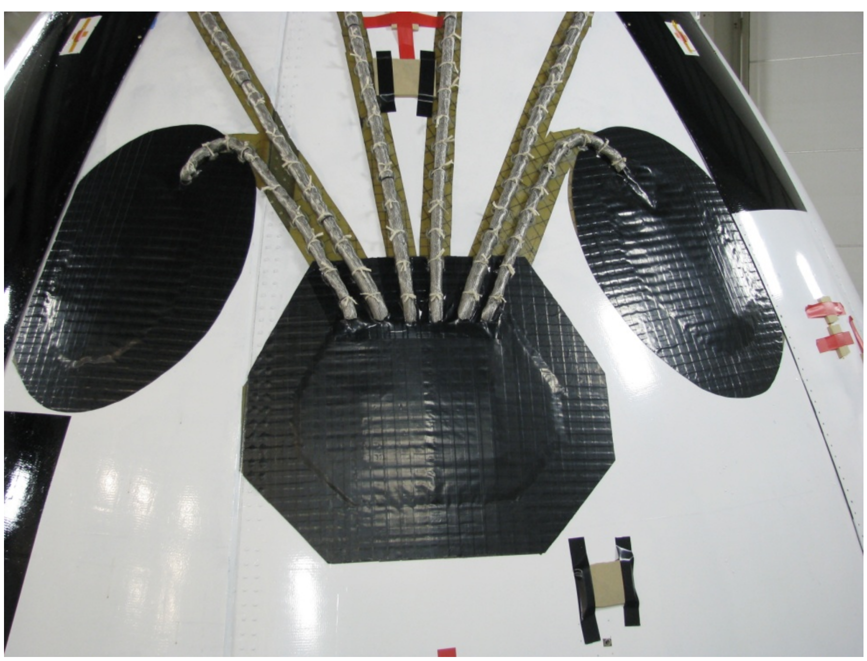


Figure 27. Final recommended mortar hole and confluence cavity covers.

FLIGHT PERFORMANCE

Confluence Opening Cover

The confluence cover was not flown due to MLAS Team concerns about the cover peeling off during ascent and causing entangling or tearing of the mission critical drogue parachutes.

Mortar Hole Opening Covers and Venting

The mortar hole covers stayed on during ascent and did not impede successful performance of the mortars or cause damage to the turn-around drogue parachutes after mortar firing. Video footage indicates that the tape cover and foam fill debris separated from the vehicle more rapidly than the drogue parachutes. Figure 28 shows an image from the Mobile Aerospace Reconnaissance System (MARS) camera system that indicates that at least one cover probably tore along the perimeter of the hole during mortar firing as was observed during the ground based mortar fire test. The forward fairing was not recovered to verify actual conditions of both hole covers or the foam fill. However, MLAS video of the FF IML shows that the mortar holes remained almost completely sealed with foam following the firing of the mortars. Figure 29 shows video stills of the FF IML before and after mortar firing. The right mortar foam insert did not displace during mortar firing. The left mortar IML foam displaced upward slightly during mortar firing. A small bright spot on the IML foam surrounding the left mortar canister indicates visibility of the external flash. The foam position remained constant throughout the remainder of the flight. However, flashes of sunlight appear at the same location during reorientation indicating a very small and probably insignificant opening was present. The opening was estimated to be less than 6 in x 1 in size.

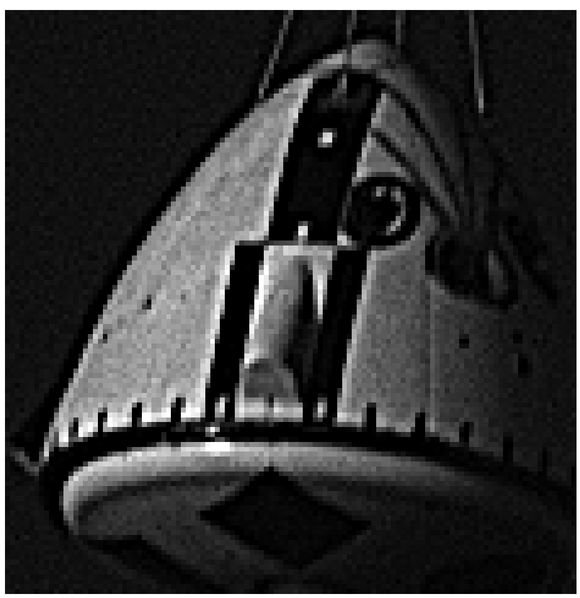
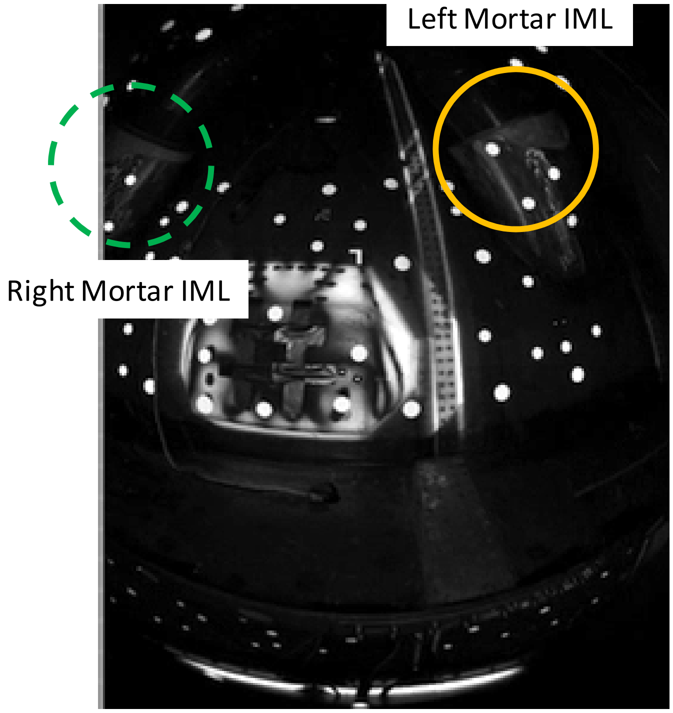
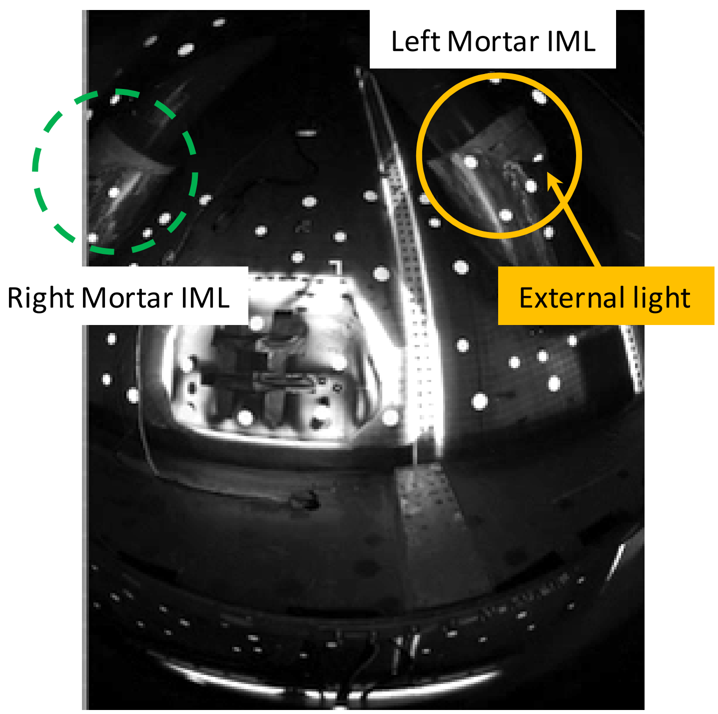


Figure 28. OML view of mortar holes following (MARS) mortar firing.



(a) IML foam around mortar canisters before mortar firing.



(b) IML foam around mortar canisters after mortar firing showing small displacement on left mortar IML foam insert.

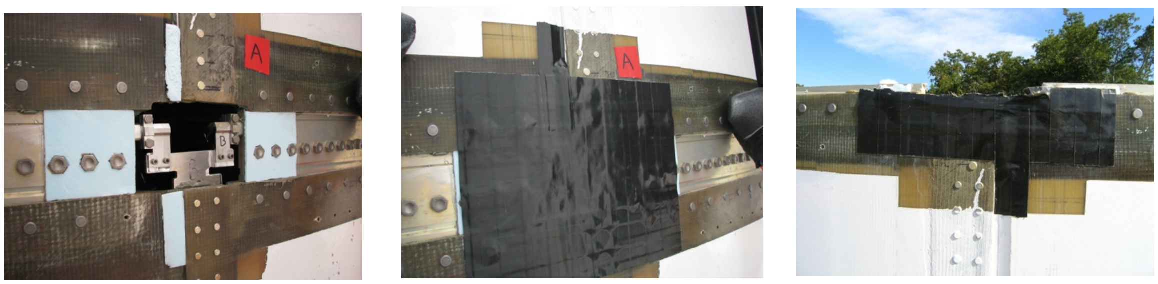
Figure 29. IML foam positions at mortar hole locations before and after mortar firing.

Separation Joint Opening Covers

All separation joints performed as designed. Figures 30 and 31 show performance of two covers. As can be seen, the covers tore along the ring separation line and parallel to the cover's fiber orientation. The covers remained fully attached though the ascent, ring separation, immersion in sea water, and, in the case of Figure 31c, ring petal separation due to impact.

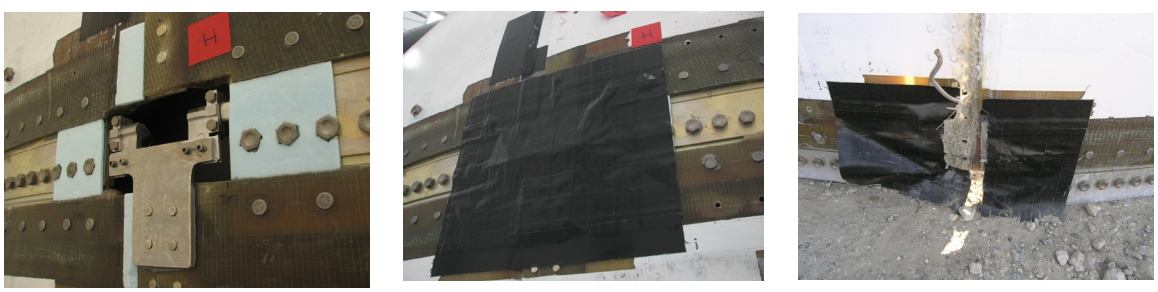
Fin Root Gap Covers

Fin root gap covers stayed intact through ascent. A typical post-flight fin root cover is shown in Figure 32. Only one fin root cover showed notable damage. The damage is consistent with fin damage sustained during boost fin impact with the sea bed and the resultant lateral bending as shown in Figure 33.



(a) Underlying foam (b) Pre-flight (c) Post-flight

Figure 30. CS-BS Separation Joint Opening at Fin I (between +Z and -Y axes).



(a) Underlying foam (b) Pre-flight (c) Post-flight

Figure 31. FF-CS Separation Joint Opening at Fin IV (between +Z and +Y axes).

SUMMARY

In summary, close-outs were required to cover openings of various sizes on the MLAS fairing to prevent aerodynamic flow-through and to maintain the MLAS OML surface shape. Two-ply duct tape covers were designed to meet these needs. The covers were analyzed and experimentally tested to demonstrate their ability to maintain integrity under anticipated vehicle ascent pressure loads and to not impede firing of the drogue chute mortars. Tape covers were layed-up on thin Teflon sheets to facilitate installation on the vehicle. Custom cut foam insulation board was used to fill mortar hole and separation joint cavities and provide support to the applied tape covers. Flight test results showed that the tape covers remained adhered during flight, and, thus, met performance expectations.

REFERENCE

[1] "NESC MLAS Final Assessment Report", NESC-RP-07-033, NASA Engineering and Safety Center, 2010.

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Figure 32. Typical undamaged fin root gap covers.

Figure 33. Minor damage to fin root gap covers.

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14. ABSTRACT
In 2007, the NASA Exploration Systems Mission Directorate (ESMD) chartered the NASA Engineering Safety Center (NESC) to demonstrate an alternate launch abort concept as risk mitigation for the Orion project's baseline "tower" design. On July 8, 2009, a full scale, passive aerodynamically stabilized Max Launch Abort System (MLAS) pad abort demonstrator was successfully launched from NASA Goddard Space Flight Center's Wallops Flight Facility. Aerodynamic close-outs were required to cover openings on the MLAS fairing to prevent aerodynamic flow-through and to maintain the MLAS OML surface shape. Two-ply duct tape covers were designed to meet these needs. The duct tape used was a high strength fiber reinforced duct tape with a rubberized adhesive that demonstrated 4.6 lb/in adhesion strength to the unpainted fiberglass fairing. Adhesion strength was observed to increase as a function of time. The covers were analyzed and experimentally tested to demonstrate their ability to maintain integrity under anticipated vehicle ascent pressure loads and to not impede firing of the drogue chute mortars. Testing included vacuum testing and a mortar fire test. Tape covers were layed-up on thin Teflon sheets to facilitate installation on the vehicle. Custom cut foam insulation board was used to fill mortar hole and separation joint cavities and provide support to the applied tape covers. Flight test results showed that the tape covers remained adhered during flight.

15. SUBJECT TERMS
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